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(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
5 July 2001 (05.07.2001)

PCT

(10) International Publication Number
WO 01/048606 A3

(51) International Patent Classification⁷: **G06F 9/54, 9/50**

(21) International Application Number: **PCT/US00/42716**

(22) International Filing Date: **8 December 2000 (08.12.2000)**

(25) Filing Language: **English**

(26) Publication Language: **English**

(30) Priority Data:
09/473,799 28 December 1999 (28.12.1999) **US**

(63) Related by continuation (CON) or continuation-in-part (CIP) to earlier application:

US 09/473,799 (CON)
Filed on 28 December 1999 (28.12.1999)

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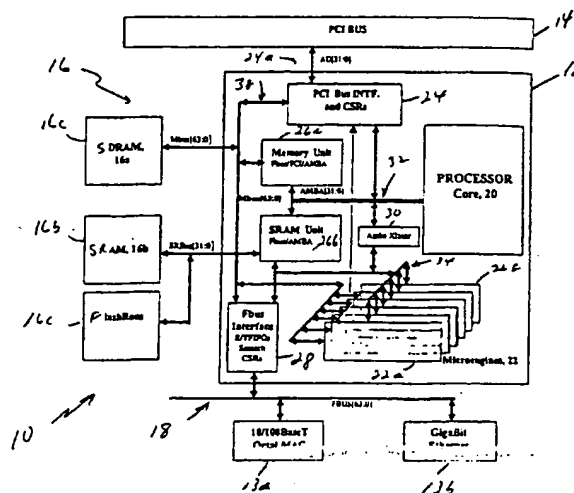
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(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: **ALLOCATION OF DATA TO THREADS IN MULTI-THREADED NETWORK PROCESSOR**



(57) Abstract: A parallel hardware-based multithreaded processor is described. The processor includes a general purpose processor that coordinates system functions and a plurality of microengines that support multiple program threads. The processor also includes a memory control system that has a first memory controller that sorts memory references based on whether the memory references are directed to an even bank or an odd bank of memory and a second memory controller that optimizes memory references based upon whether the memory references are read references or write references. A program thread communication scheme for packet processing is also described.



Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(88) Date of publication of the international search report:

11 July 2002

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 00/42716

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G06F9/54 G06F9/50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

INSPEC, EPO-Internal, IBM-TDB, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	DOUGLAS C. SCHMIDT, TATSUYA SUDA: "The Performance of Alternative Threading Architectures for Parallel Communication Subsystems" INTERNET DOCUMENT, 'Online! 13 November 1998 (1998-11-13), XP002181062 Retrieved from the Internet: <URL:http://www.cs.wustl.edu/{schmidt/PDF/JCDC-96.pdf}> 'retrieved on 2001-10-23! page 1, right-hand column, line 19 - line 34 page 2; figure 1 page 3, left-hand column, line 1 - line 24; figure 2	1-3,5-7, 9,16-19, 22,23, 25,26
A	& "Index of /{schmidt/PDF"	
L	INTERNET DOCUMENT, 'Online! 5 October 2001 (2001-10-05), XP002181066 Retrieved from the Internet: <URL:http://www.cs.wustl.edu/{schmidt/PDF/-/--	4,8,20, 27



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G document member of the same patent family

Date of the actual completion of the international search

19 December 2001

Date of mailing of the international search report

16/01/2002

Name and mailing address of the ISA

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INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 00/42716

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P,X	<p>> 'retrieved on 2001-10-24! page 4, line 9</p> <p>---</p> <p>KEMATHAT VIBHATAVANIJ, NIAN-FENG TZENG, ANGKUL KONGMUNVATTANA: "Simultaneous Multithreading-Based Routers" PROCEEDINGS OF THE 2000 INTERNATIONAL CONFERENCE ON PARALLEL PROCESSING, 21 - 24 August 2000, pages 362-369, XP002181063 Toronto, Ontario, Canada</p>	1-3,5-7, 9,16-19, 22,23, 25,26
A	<p>abstract</p> <p>page 362, right-hand column, line 17 -page 363, left-hand column, line 25 page 369, left-hand column, line 44 - last line page 369, right-hand column, line 3 - line 6</p>	4,8,20, 27
X	<p>---</p> <p>JONATHAN TURNER, GURU PARULKAR, DAN DECASPER, JOHN DEHART, SUMI CHOI, TILMAN WOLF, BERNHARD PLATTNER, RALPH KELLER: "Design of a High Performance Active Router" INTERNET DOCUMENT, 'Online! 18 March 1999 (1999-03-18), XP002181064 Retrieved from the Internet: <URL:http://www.arl.wustl.edu/arl/projects /ann/slides/ann.pdf> 'retrieved on 2001-10-23!</p>	1,16,22
A	<p>page 6</p> <p>page 8 -page 9 page 18</p>	2-15, 17-21, 23-28
A	<p>---</p> <p>GOMEZ J C ET AL: "EFFICIENT MULTITHREADED USER-SPACE TRANSPORT FOR NETWORK COMPUTING:DESIGN AND TEST OF THE TRAP PROTOCOL" JOURNAL OF PARALLEL AND DISTRIBUTED COMPUTING, ACADEMIC PRESS, DULUTH, MN, US, vol. 40, no. 1, 10 January 1997 (1997-01-10), pages 103-117, XP000682840 ISSN: 0743-7315 abstract page 107, left-hand column, line 20 -page 109, left-hand column, line 31</p> <p>-----</p>	1,4, 10-16, 20-22, 27,28

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
5 July 2001 (05.07.2001)

PCT

(10) International Publication Number
WO 01/48596 A2

- (51) International Patent Classification⁷: **G06F 9/00**
- (21) International Application Number: **PCT/US00/33395**
- (22) International Filing Date: **8 December 2000 (08.12.2000)**
- (25) Filing Language: **English**
- (26) Publication Language: **English**
- (30) Priority Data:
09/473,798 28 December 1999 (28.12.1999) **US**
- (63) Related by continuation (CON) or continuation-in-part (CIP) to earlier application:
US 09/473,798 (CON)
Filed on 28 December 1999 (28.12.1999)
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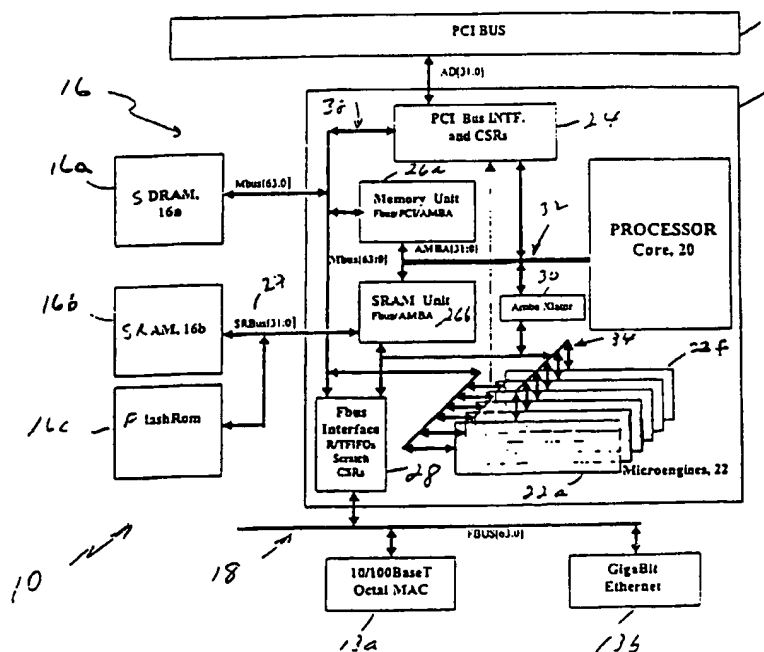
(74) Agent: **HARRIS, Scott, C.; Fish & Richardson P.C., 4350 La Jolla Village Drive, Suite 500, San Diego CA 92122 (US).**

(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States (*regional*): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European

[Continued on next page]

(54) Title: **READ LOCK MISS CONTROL IN A MULTITHREADED ENVIRONMENT**



(57) Abstract: Managing memory access to random access memory includes fetching a read lock memory reference request and placing the read lock memory reference request at the end of a read lock miss queue if the read lock memory reference request is requesting access to an unlocked memory location and the read lock miss queue contains at least one read lock memory reference request.



patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Published:

- *Without international search report and to be republished upon receipt of that report.*

READ LOCK MISS CONTROL IN A MULTITHREADED ENVIRONMENTBACKGROUND OF THE INVENTION

This invention relates to read lock memory references.

When a computer instruction (thread) needs access to a
5 memory location in the computer, it goes to a memory
controller. A memory reference instruction may request a
read lock on a particular memory location. The read lock
prevents other instructions from accessing that memory
location until a read unlock instruction for that memory
10 location gets granted.

SUMMARY OF THE INVENTION

According to one aspect of the invention, a method is
described of managing memory access to random access memory
includes fetching a read lock memory reference request and
15 placing the read lock memory reference request at the end
of a read lock miss queue if the read lock memory reference
request is requesting access to an unlocked memory location

and the read lock miss queue contains at least one read lock memory reference request.

Other advantages will become apparent from the following description and from the claims.

5

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a communication system employing a hardware-based multithreaded processor.

FIG. 2 is a block diagram of a memory controller for latency limited operations used in the hardware-based
10 multithreaded processor.

FIG. 3 is a flowchart of the operation of a memory controller in the hardware-based multithreaded processor.

FIG. 4 is a flowchart of the operation of a memory controller in the hardware-based multithreaded processor.

15

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, a communication system 10 includes a parallel, hardware-based multithreaded processor 12. The hardware-based multithreaded processor 12 is coupled to a bus such as a peripheral component

interconnect (PCI) bus 14, a memory system 16, and a second bus 18. The system 10 is especially useful for tasks that can be broken into parallel subtasks or functions.

Specifically, a hardware-based multithreaded processor 12
5 is useful for tasks that are bandwidth oriented rather than latency oriented. The hardware-based multithreaded processor 12 has multiple microengines 22a-22f, each with multiple hardware controlled threads that can be simultaneously active and independently work on a task.

10 The hardware-based multithreaded processor 12 also includes a central controller 20 that assists in loading microcode control for other resources of the hardware-based multithreaded processor 12 and performs other general purpose computer type functions such as handling protocols,
15 exceptions, and extra support for packet processing where the microengines 22a-22f pass the packets off for more detailed processing such as in boundary conditions. In one embodiment, the processor 20 is a Strong Arm® (Arm is a trademark of ARM Limited, United Kingdom) based
20 architecture. The general purpose microprocessor 20 has an operating system. Through the operating system the processor 20 can call functions to operate on microengines 22a-22f. The processor 20 can use any supported operating

system, preferably a real time operating system. For the core processor implemented as a Strong Arm architecture, operating systems such as, MicrosoftNT real-time, VXWorks and μ CUS, a freeware operating system available over the Internet, can be used.

The hardware-based multithreaded processor 12 also includes a plurality of function microengines 22a-22f. Functional microengines (microengines) 22a-22f each maintain a plurality of program counters in hardware and states associated with the program counters. Effectively, a corresponding plurality of sets of threads can be simultaneously active on each of the microengines 22a-22f while only one is actually operating at any one time.

In one embodiment, there are six microengines 22a-22f as shown. Each microengines 22a-22f has capabilities for processing four hardware threads. The six microengines 22a-22f operate with shared resources including memory system 16 and bus interfaces 24 and 28. The memory system 16 includes a Synchronous Dynamic Random Access Memory (SDRAM) controller 26a and a Static Random Access Memory (SRAM) controller 26b. SDRAM 16a and SDRAM controller 26a are typically used for processing large volumes of data, e.g., processing of network payloads from network packets.

SRAM 16b and SRAM controller 26b are used in a networking implementation for low latency, fast access tasks, e.g., accessing look-up tables, memory for the core processor 20, and so forth.

5 The six microengines 22a-22f access either the SDRAM 16a or SRAM 16b based on characteristics of the data. Thus, low latency, low bandwidth data is stored in and fetched from SRAM 16b, whereas higher bandwidth data for which latency is not as important, is stored in and fetched
10 from SDRAM 16a. The microengines 22a-22f can execute memory reference instructions to either the SDRAM controller 26a or the SRAM controller 26b.

Advantages of hardware multithreading can be explained by SRAM or SDRAM memory accesses. As an example, an SRAM
15 access requested by a Thread_0, from a microengine 22a-22f will cause the SRAM controller 26b to initiate an access to the SRAM 16b. The SRAM controller 26b controls arbitration for the SRAM bus 27, accesses the SRAM 16b, fetches the data from the SRAM 16b, and returns data to the requesting
20 microengine 22a-22f. During an SRAM 16b access, if the microengine, e.g., 22a, had only a single thread that could operate, that microengine would be dormant until data was returned from the SRAM 16b. The hardware context swapping

within each of the microengines 22a-22f enables other contexts with unique program counters to execute in that same microengine. Thus, another thread, e.g., Thread_1, can function while the first thread, e.g., Thread_0, is awaiting the read data to return. During execution, Thread_1 may access the SDRAM memory 16a. While Thread_1 operates on the SDRAM unit 26a, and Thread_0 is operating on the SRAM unit 26b, a new thread, e.g., Thread_2, can now operate in the microengine 22a. Thread_2 can operate for a certain amount of time until it needs to access memory or perform some other long latency operation, such as making an access to a bus interface. Therefore, simultaneously, the processor 12 can have a bus operation, SRAM operation, and SDRAM operation all being completed or operated upon by one microengine 22a and have one more thread available to process more work in the data path.

The hardware context swapping also synchronizes completion of tasks. For example, two threads could hit the same shared resource, e.g., SRAM 16b. Each one of these separate functional units, e.g., the FBUS interface 28, the SRAM controller 26b, and the SDRAM controller 26a, when they complete a requested task from one of the microengine thread contexts reports back a flag signaling

completion of an operation. When the flag is received by the microengine 22a-22f, the microengine 22a-22f can determine which thread to turn on.

One example of an application for the hardware-based multithreaded processor 12 is as a network processor. As a network processor, the hardware-based multithreaded processor 12 interfaces to network devices such as a media access controller device, e.g., a 10/100BaseT Octal MAC 13a or a Gigabit Ethernet device 13b. In general, as a network processor, the hardware-based multithreaded processor 12 can interface to any type of communication device or interface that receives/sends large amounts of data. If communication system 10 functions in a networking application, it could receive a plurality of network packets from the devices 13a, 13b and process those packets in a parallel manner. With the hardware-based multithreaded processor 12, each network packet can be independently processed.

Another example for use of processor 12 is a print engine for a postscript processor or as a processor for a storage subsystem, i.e., RAID disk storage. A further use is as a matching engine. In the securities industry for example, the advent of electronic trading requires the use

of electronic matching engines to match orders between buyers and sellers. These and other parallel types of tasks can be accomplished on the system 10.

Each of the functional units, e.g., the FBUS interface 5 28, the SRAM controller 26b, and the SDRAM controller 26a, are coupled to one or more internal buses. The internal buses are dual, 32-bit buses (i.e., one bus for read and one for write). The hardware-based multithreaded processor 12 also is constructed such that the sum of the bandwidths 10 of the internal buses in the processor 12 exceeds the bandwidth of external buses coupled to the processor 12. The processor 12 includes an internal core processor bus 32, e.g., an ASB bus (Advanced System Bus), that couples the processor core 20 to the memory controller 26a, 26b and 15 to an ASB translator 30. The ASB bus 32 is a subset of the so-called AMBA bus that is used with the Strong Arm processor core. The processor 12 also includes a private bus 34 that couples the microengine units to SRAM controller 26b, ASB translator 30, and FBUS interface 28. 20 A memory bus 38 couples the memory controllers 26a, 26b to the bus interfaces 24 and 28 and memory system 16 including a flashrom 16c used for boot operations and so forth.

Referring to FIG. 2, the SRAM controller 26b for the SRAM 16b is shown. The SRAM controller 26b includes an address and command queue 120. SRAM controller 26b is optimized based on the type of memory operation, i.e., a read or a write. The address and command queue 120 includes a high priority queue 120a (holding memory reference requests from high priority tasks), a read queue 120b (holding read memory reference requests, which are the predominant memory reference functions that an SRAM performs), and an order queue 120c (holding, in general, all writes to SRAM 16b and reads that are to be non-optimized). Although not shown, the address and command queue 120 could also include a write queue. An insert queue control unit 132 of control logic determines where to queue each memory request from the microengines 22a-22f. An arbitration scheme in a remove queue arbitration unit 124 of control logic determines the processing order of the memory reference requests in the queues 120.

The SRAM controller 26b also includes core bus interface logic, e.g., ASB bus 122. The ASB bus interface logic 122 interfaces the core processor 20 to the SRAM controller 26b. The ASB bus 122 is a bus that includes a 32-bit data path and a 28-bit address path. The data is

accessed to and from memory 16b through an MEM
(microelectromechanical) ASB data device 128, e.g., a
buffer. The MEM ASB data device 128 is a queue for write
data. If there is incoming data from the core processor 20
5 via ASB interface 122, the data can be stored in the MEM
ASB data device 128 and subsequently removed from the MEM
ASB data device 128 through an SRAM interface 140 to SRAM
memory 16b. Although not shown, the same queue structure
can be provided for reads.

10 The memory requests are sent to SRAM interface 140 via
a multiplexer 126. The multiplexer 126 is controlled by an
SRAM arbiter 131 which detects the fullness of each of the
queues and the status of the requests and from that decides
priority based on a programmable value stored in a priority
15 service control register 130. Once control to the
multiplexer 126 selects a memory reference request, the
memory reference request is sent to a command decoder and
address generator 138 where it is decoded and an address is
generated.

20 The SRAM controller 26b maintains control of the
Memory Mapped off-chip SRAM and Expansion ROM. The SRAM
controller 26b can address, e.g., 16 MBytes, with, e.g., 8
MBytes mapped for SRAM 16b, and 8 MBytes reserved for

special functions including: Boot space via flashrom 16c; and Console port access for MAC devices 13a, 13b and access to associated (RMON) counters. The SRAM is used for local look-up tables and queue management functions.

- 5 The SRAM controller 26b supports the following transactions:

Microengine requests (via private bus) to/from SRAM.
Core Processor (via ASB bus) to/from SRAM.

10

- The SRAM controller 26b performs memory reference sorting to minimize delays (bubbles) in the pipeline from the SRAM interface 140 to memory 16b. The SRAM controller 26b does memory reference sorting based on the read
15 function. A bubble can either be one or two cycles depending on the type of memory device employed.

- The SRAM controller 26b includes a lock look-up device 142, an eight-entry address content addressable memory (CAM) for look-ups of read locks. Each position includes a
20 valid bit that is examined by subsequent read lock requests. The address and command queue 120 also includes a read lock miss (fail) queue 120d. The read lock miss
queue 120d is used to hold up to twenty-four read requests

that fail because of a lock existing on the portion of memory requested to be read. One of the microengines 22a-22f issues a read lock memory reference request that is processed in address and control queue 120.

5 Referring to FIG. 3, a memory reference request is processed 51 by the controller 26b. The controller 26b receives 50 a memory reference request on either the order queue 120c or the read queue 120b. The command decoder and address generator 138 determines 52 whether the memory
10 reference request is a "read" request, a write request, a "read lock" request, or a write unlock ("unlock") request. If the command decoder and address generator 138 determines 52 that the request is a read request, then the command decoder and address generator 138 enters 54 the lock into
15 the lock look-up device 142 so that subsequent read lock requests will find the memory location locked. Lock requests cannot be processed on that locked memory location until an unlock request from a microengine 22a-22f unlocks 58 that memory location.

20 If the command decoder and address generator 138 determines 52 that the memory reference request is a read lock request, the controller 26b will access 56 lock look-up device 142 to determine whether this memory location is

already locked. The access 56 determines whether the read lock request gets performed 62 or enters 64 the read lock miss queue 120d where it waits for the memory location to be unlocked.

5 If the memory location is locked from any prior lock request, the read lock request fails and gets stored 64 at the end of the read lock miss queue 120d. The controller 26b proceeds to receive 50 the next request.

10 If the memory location is unlocked, the lock look-up device 142 checks 60 to see if the read lock miss queue 120d is empty. If the read lock miss queue 120d is empty, that indicates that there are no previous read lock requests awaiting processing. Thus, the read lock request will be processed: the address of the memory reference will
15 be used by the SRAM interface 140 to perform 62 an SRAM address read/write request to memory 16b and subsequently lock the memory location. Then the controller 26b receives 50 the next request.

20 If the read lock miss queue 120d is not empty, that indicates that there is at least one prior read lock request awaiting processing. To ensure a first-in/first-out order of processing the read lock requests, the read lock request will be stored 64 at the end of the read lock miss queue.

miss queue 120d. Read lock requests continue queuing in the read lock miss queue 120d until the controller 26b receives 50 an unlock request and recognizes 52 it as such. A memory location is unlocked by operation of a

5 microcontrol instruction in a program after the need for the lock has ended. Once the unlock request is received 50, the memory location is unlocked 58 by clearing the valid bit in the CAM 142. After the unlock 58, the read lock fail queue 120d becomes the highest priority queue

10 120, giving all queued read lock misses a chance to issue a memory lock request.

Referring to FIG. 4, the read lock miss queue 120d is tested 69 to see if the head of the read lock miss queue 120d may be granted its lock. The testing 69 will continue

15 until the read lock miss queue 120d fails to provide a grant or until there are no more entries in the read lock miss queue 120d. The highest priority is given to the read lock miss queue 120d by letting it win 70 the next arbitration in the remove queue arbitration unit 124. The

20 lock look-up device 142 checks 72 to see if the top read lock request (the one stored first in the read lock miss queue 120d) is requesting to read an unlocked memory location. If the read lock request is for a locked

location, the read lock miss queue 120d remains as it is to ensure the first-in/first-out order described above, and the testing 69 ends 78. If the read lock request is for an unlocked location, the address of the memory reference will
5 be used by the SRAM interface 140 to perform 74 an SRAM address read/write request to memory 16b. After performing 74, the lock look-up device 142 checks 76 to see if the read lock miss queue 120d is empty. If it is empty, the testing 69 ends 78. Otherwise, the testing 69 continues
10 with the read lock miss queue 120d winning 70 another arbitration in the remove queue arbitration unit 124.

Other embodiments are within the scope of the following claims.

What is claimed is:

1. A method of managing memory access to random access memory comprises:

fetching a read lock memory reference request; and

5 placing the read lock memory reference request at the end of a read lock miss queue if the read lock memory reference request is requesting access to an unlocked memory location and the read lock miss queue contains at least one read lock memory reference request.

10 2. The method of claim 1 in which the random access memory is located in a parallel, hardware-based multithreaded processor.

3. The method of claim 1 in which the random access memory comprises a static random access memory.

15 4. The method of claim 1 further comprises placing the read lock memory reference at the end of a read lock miss queue if the read lock memory reference request is requesting access to a locked memory location.

5. The method of claim 1 further comprises removing
20 the read lock memory reference requests from the read lock

miss queue in the order in which they were placed in the read lock miss queue.

6. The method of claim 1 in which the read lock memory reference request is fetched from a read queue.

5 7. The method of claim 1 in which the read lock memory reference request is fetched from an order queue.

8. The method of claim 1 in which the read lock miss queue contains a number of entries equal to a number of contexts that may execute the read lock memory reference
10 requests minus one.

9. The method of claim 1 further comprises placing a read lock memory reference request in a queue that contains a read lock memory reference request requesting access to the same memory location.

15 10. An article comprising a computer-readable medium which stores computer-executable instructions for managing memory access to random access memory, the instructions causing a computer to:

fetch a read lock memory reference request; and
20 place the read lock memory reference request at the

end of a read lock miss queue if the read lock memory reference request is requesting access to an unlocked memory location and the read lock miss queue contains at least one read lock memory reference request.

5 11. The article of claim 10 in which the random access memory is located in a parallel, hardware-based multithreaded processor.

 12. The article of claim 10 in which the random access memory comprises a static random access memory.

10 13. The article of claim 10 in which the instructions further cause a computer to place the read lock memory reference request at the end of a read lock miss queue if the read lock memory reference request is requesting access to a locked memory location.

15 14. The article of claim 10 in which the instructions further cause a computer to remove the read lock memory reference requests from the read lock miss queue in the order in which they were placed in the read lock miss queue.

15. The article of claim 10 in which the read lock memory reference request is fetched from a read queue.

16. The article of claim 10 in which the read lock memory reference request is fetched from an order queue.

5 17. The article of claim 10 in which the read lock miss queue contains a number of entries equal to a number of contexts that may execute the read lock memory reference requests minus one.

18. The article of claim 10 in which the instructions
10 further cause a computer to place a read lock memory reference request in a queue that contains a read lock memory reference request requesting access to the same memory location.

19. A controller for managing access to random access
15 memory comprises:

an address content addressable memory that supports locked locations in memory; and

a read lock miss queue that stores read lock memory reference requests that request access to memory locations
20 unlocked in the address content addressable memory when the read lock miss queue contains at least one entry.

20. The controller of claim 19 in which the random access memory is located in a parallel, hardware-based multithreaded processor.

21. The controller of claim 19 in which the random
5 access memory comprises a static random access memory.

22. The controller of claim 19 in which the read lock memory reference requests are stored at the end of the read lock miss queue if the read lock memory reference request requests access to a locked memory location.

10 23. The controller of claim 19 in which the read lock memory reference requests are removed from the read lock miss queue in the order in which they were placed in the read lock miss queue.

24. The controller of claim 19 in which the read lock
15 miss queue contains a number of entries equal to a number of contexts that may execute the read lock memory reference requests minus one.

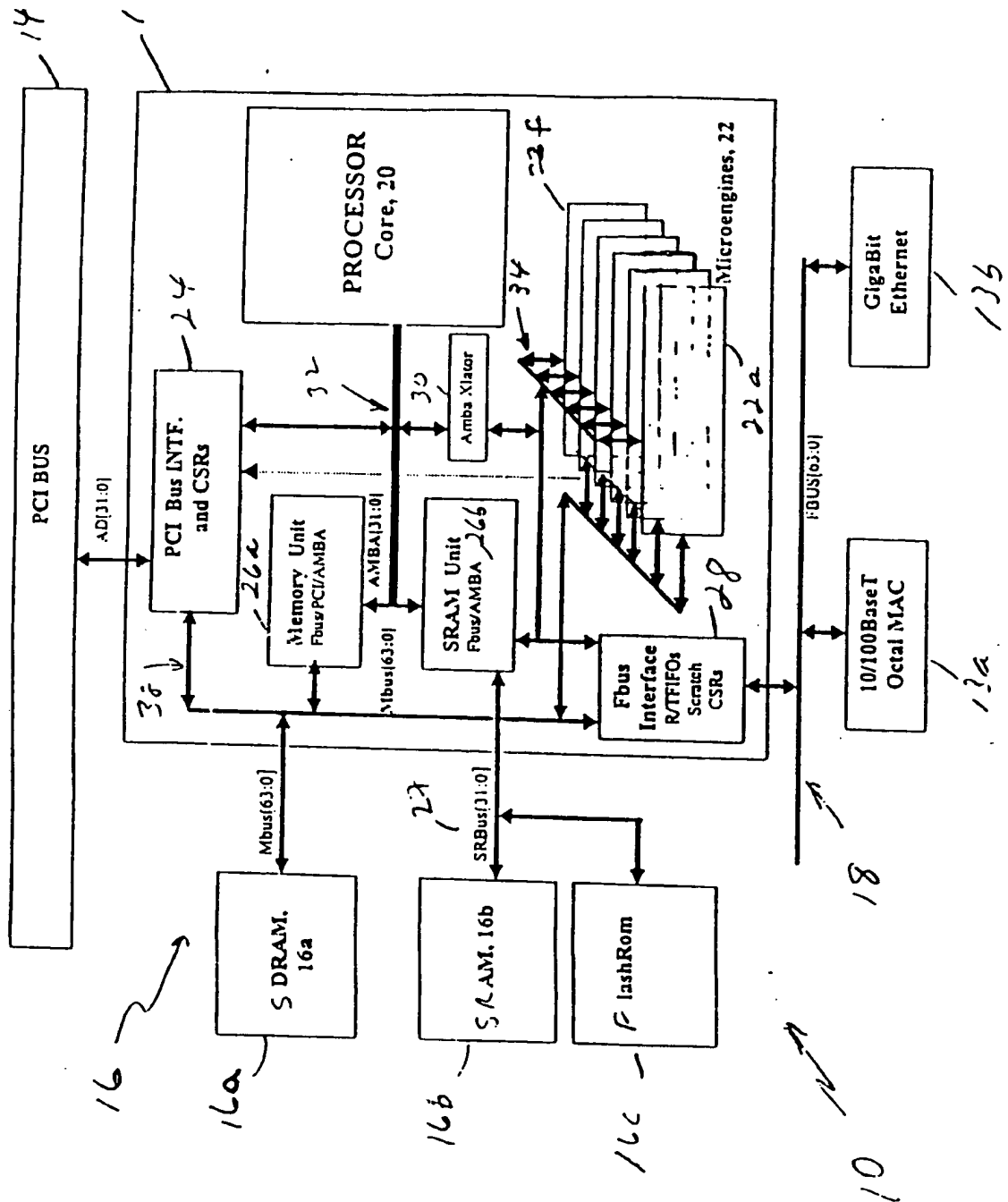


FIG. 1

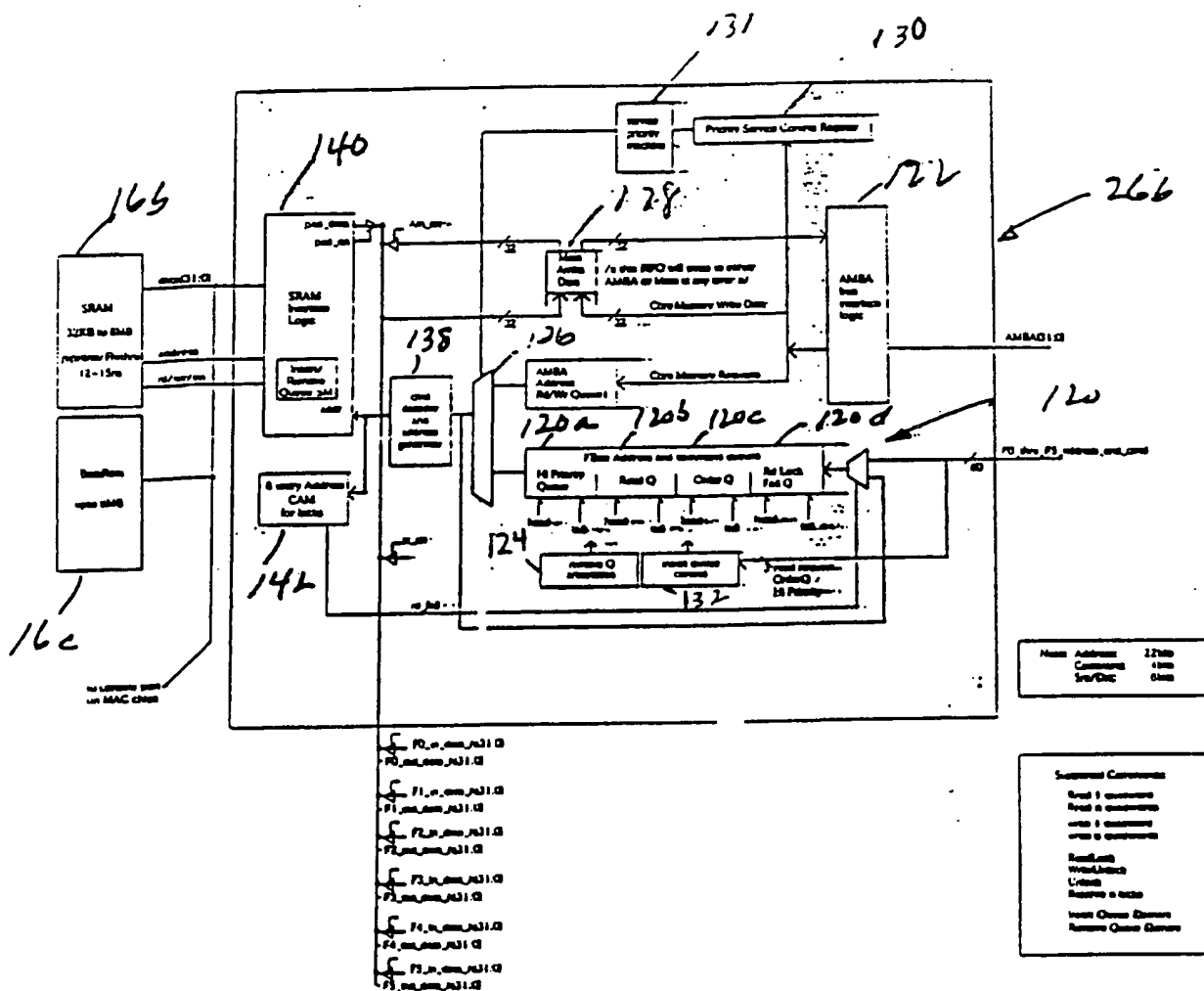


FIG. 2

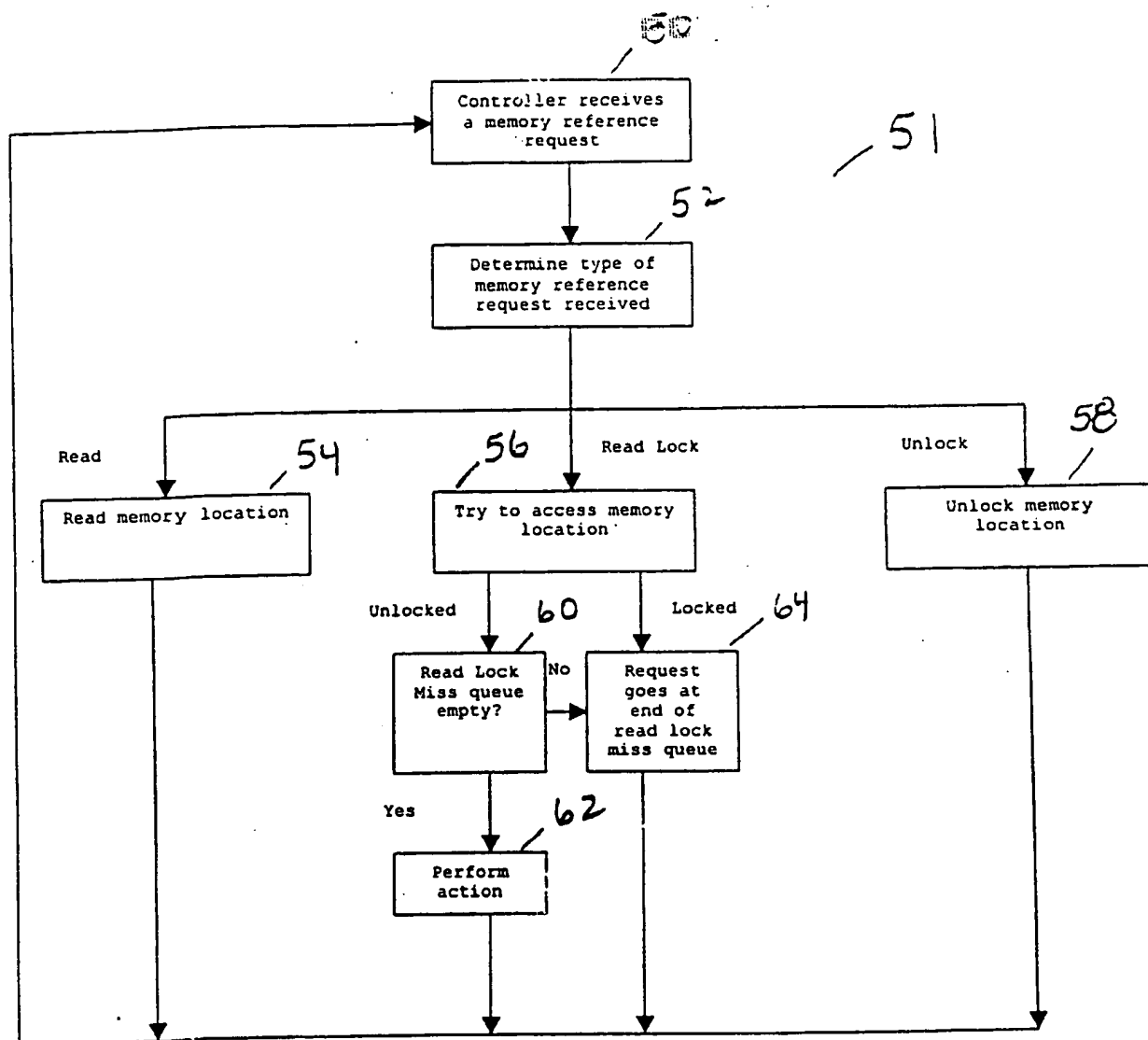


FIG. 3

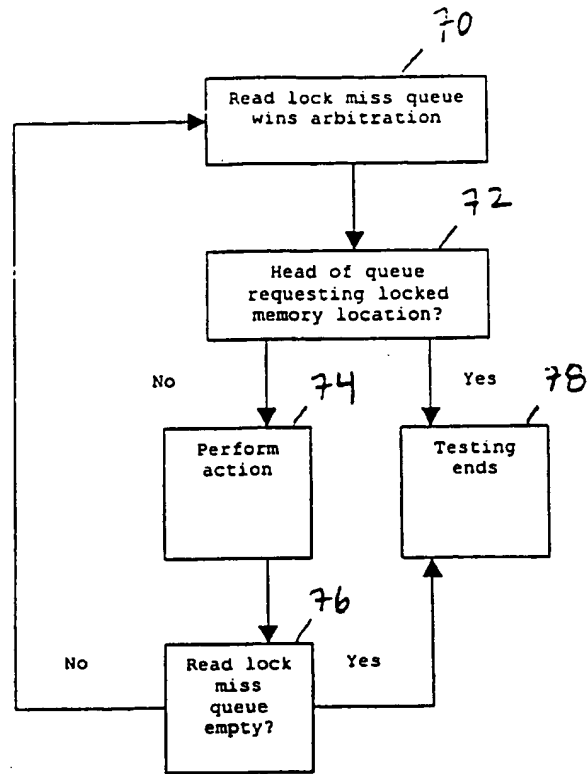


FIG. 4